NATIONAL SECURITY/EMERGENCY PREPAREDNESS AND DISASTER RECOVERY COMMUNICATIONS VIA ACTS

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1. ABSTRACT

During the period from early 1993 through 1994, the U.S. National Communication System, a government agency, sponsored the development and execution of several fixed and mobile experiments using the Advanced Communications Technology Satellite (ACTS). The purpose of these experiments was to evaluate the feasibility of integrating an ACTS like communications system into National Security/Emergency Preparedness (NS/EP) operational scenarios. These experiments focused on clear and secure voice communications in both the fixed and mobile environment. For the mobile experiments, the focus was on the performance of both clear and secure voice in the land-mobile satellite communications channel. For the fixed experiments, the focus was on the use of a TI terminal for restoration of communication services in the event of a disaster and for remote user communications. The results of these experiments are described in this paper.

2. INTRODUCTION

The NCS is commissioned by the U.S. Government to seek out and provide NS/EP and disaster recovery communications for various organizations within the Government. To this end, the NCS envisions satellite communications as providing an excellent means to accomplish this task. The NCS is constantly evaluating new and exciting technologies in satellite communications that can improve and increase their communication capabilities.

This paper describes a series of experiments that the NCS accomplished utilizing an excellent satellite of opportunity, ACTS, and several of their ground terminals: the ACTS Mobile Terminal (AMT) and the T1 VSAT. These tests were conducted by the NCS, with support from JPL, the Mitre Corporation, and the National Aeronautics and Space Administration (NASA). The overall goal of these tests was to evaluate the potential of K/Ka-band (20/30 GHz) satellite communications in general, and ACTS in particular to meet the communication needs of the NCS for the NS/EP community. The mobile experiments evaluated the performance of both clear and secure voice in the K/Ka-band land-mobile satellite communications channel. The fixed experiments evaluated the use of the T1-VSAT capabilities for use in communications restoration following a disaster and for remote user communications.

The organization of this paper is organized as follows, The particulars of the Mobile Secure experiments are provided in Section Three, Details on each of the three T1-VSAT experiments performed are provided in Sections Four, Five, and Six, respectively. These sections include the experiment objectives, the experiment setup, a brief summary of the collected data and analysis, and finally, any conclusions that may be drawn from this data. A brief discussion of the T1-VSAT propagation effects is included in Section Seven. General conclusions on all of these ACTS experiments, and their ability to support the communication needs of the NCS are reported on in Section Eight.

3. SECURE MOBILE COMMUNICATIONS WITH THE AMT

3.1 Objectives

The primary objective of the mobile experiments involving the AMT was to demonstrate the capability of ACTS, in conjunction with the AMT, to provide operationally consistent secure voice communications at 2.4 kbps and 4.8 kbps between Secure Telephone Units, Version Ill (STU-III's). Figure 3-1 contains a depiction of the experiment configuration, The complete experiment plan can be found in [1].

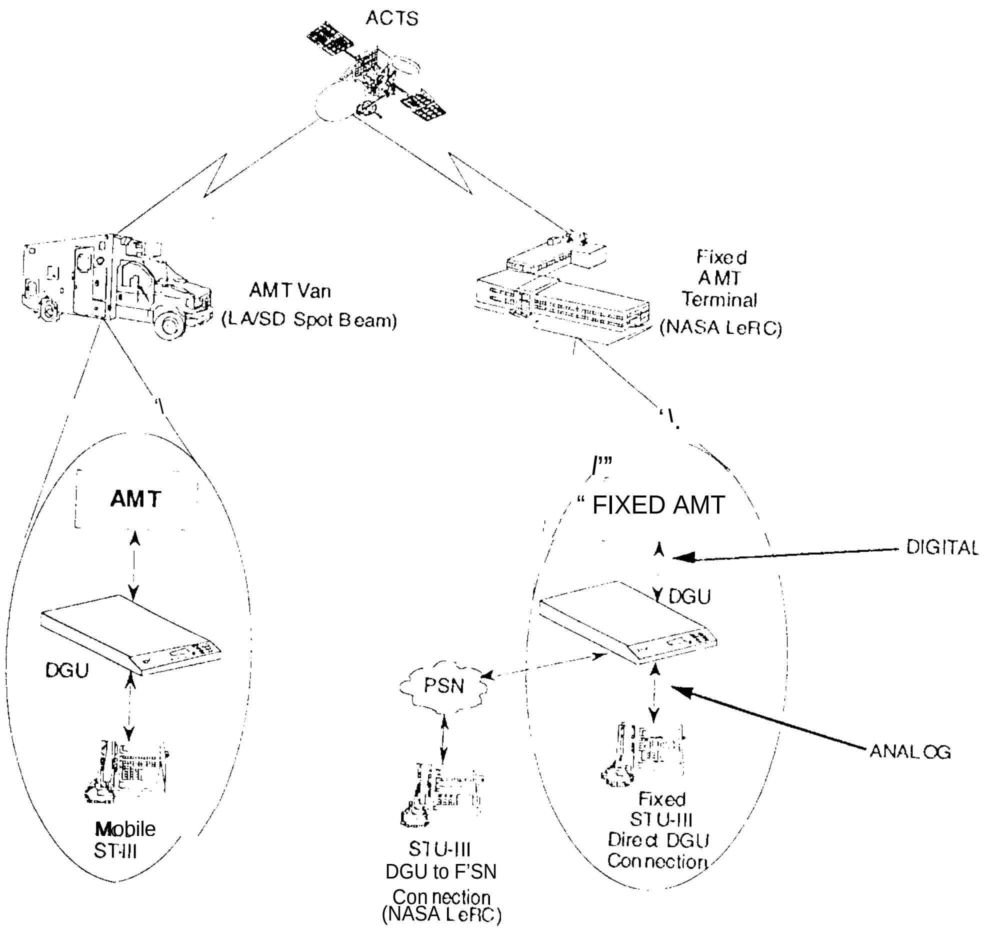

Figure 3-l Secure Mobile Communications Experiment Configuration

Two types of communication channels were tested, The first was a mobile to fixed station communications channel. The second extended the first channel to include the Public Switched Telephone Network (PSN). For both communications channels, the key areas of interest included the following:

1) The ability to establish standard clear voice (i. e., 2 wire analog PSN phone) Communications,
2) The ability to establish and maintain secure voice communications
3) The ability to return to clear voice communications.
4) Voice quality for items 1) and 3).

3,2 **Experiment Setup**

The major components of this configuration are the STU-III telephones. the Digital Gateway Units (DGU's). the AMT and its accompanying fixed station. and ACTS. The model number and manufacturer of the STU-III telephones selected for use during these tests were Motorola Sectel 1500's, These are standard STU-III's that are in common use within the U.S. Government today. The DGU's are produced by Ilex Corporation Their functionality will be described in the following section,

The satellite connectivity was provided via ACTS and the AMT. A description of the full-duplex communication link operation is as follows. For the forward link (fixed station-to-ACTS-to-mobile terminal), two signals are provided: a pilot tone and a data/voice signal. The uplink center frequency is 29.634 GHz (the pilot tone was transmitted at an uplink frequency of 29,631 GHz). The translated downlink frequency was 19.914 GHz (the pilot tone's downlink frequency was at 19.911 GHz). The chosen transmit and receive frequencies may be tuned over a 300 MHz bandwidth. The pilot signal is used by the mobile terminal for many functions, the most prominent of which is to aid in tracking by the vehicular, steered antenna. Further details of the AMT and the basic satellite experiment configuration can be found in [2],

For the return link (mobile terminal-to-ACTS-to-fixed station) only a single data signal was transmitted. The satellite's connectivity was between the Cleveland fixed beam, illuminating NASA LeRC in Cleveland, Ohio, and the Los Angeles/San Diego spotbeam, where the mobile terminal's base location was JPL in Pasadena, California, Communications were accomplished at 2.4 kbps and 4.8 kbps. In addition to originatiordterrnination of communications at the fixed station itself, a second option existed: to pass the signal through to the PSN to a remotely located end-user. STU-III's were utilized in the mobile terminal, fixed station, or by the remotely located end-user utilizing a DGU as the interfacing gateway to the communications link, Typically, the signal levels at both the mobile terminal and the fixed station were set to ensure a $1x1\ 0^{-6}$ BER or better communications link for clear line-of-sight (LOS).

The interface device between the AMT and the STU-III, the fixed station and the STU-III, and the fixed station and the PSN was a DGU. This device is required because the two wire analog STU-III interface is not compatible with the digital interface of the satellite terminal (serial, digital RS-232 data). The STU-III output/input is either: (1) clear voice data, compatible with analog voice signaling typical of a plain old telephone (POT), or (2) secure voice data, analogous to the typical data output/input to a standard computer modern.

When operating in clear voice mode, the DGU accepts the analog voice signal from the STU-III. Using the U. S. Government standard Code Excited Linear Predictive (CELP) voice compression algorithm for 4.8 kbps communications, and the U. S. Government standard Linear Predictive Code (LPC-10) algorithm for 2.4 kbps voice, the voice signal is converted (in the DGU) to a digital data stream, This data is transmitted to the AMT terminal controller (TC) as an RS-232 signal.

When operating in the secure voice mode, the ST U-111'S use a CELP voice compression algorithm for 4.8 kbps communications, and a LPC-10 algorithm for 2.4 kbps voice. The digital data is then transmitted from the STU-III with the V.32 modem communication standard for 4.8 kbps and 9.6 kbps rates and the V.26 modem communications standard for the 2,4 kbps rate. The DGU acts as a data converter to translate between the V.32 or V.26 modem signals from the STU-III and the appropriate RS-232 data rate for input to the AM1 modem.

3.3 **Data Summary**

This section contains an analysis of the data collected during satellite field tests. Two areas of interest were explored. First, the call success/failure rates were examined. Aspects of the calls that were considered included: (1) the call set up success rate, (2) clear voice to secure communications transition success rate, and (3), the success rate of transitioning from secure calls to clear voice (this includes all calls that were both successful and unsuccessful at establishing secure communications). The second area of interest to be examined was voice quality during each of these modes of operation.

As a part of the internal AMT experiments, a series of pilot-only propagation tests were performed over the stretch of highway used for this experiment. This test run resulted in relatively stable signal levels, except for several brief, but deep shadowing events (> 20 dB). These shadowing events were due to overpasses that completely blocked the mobile terminal's view of the satellite, A secondary suburban route was also tested. It is characterized by considerable shadowing and blockages for much of the route.

A plot of typical shadowing events from one of these tests runs is shown in Figure 3-2, where the received pilot level at the mobile unit is plotted as a function of time. The data used to generate this figure was recorded in a Category II environment as defined in [3]. Category II is defined as a broad suburban thoroughfare lined with trees and buildings. The tree canopies cause intermittent blockage and the buildings are either too far removed from the road side or not tall enough to cause significant blockage.

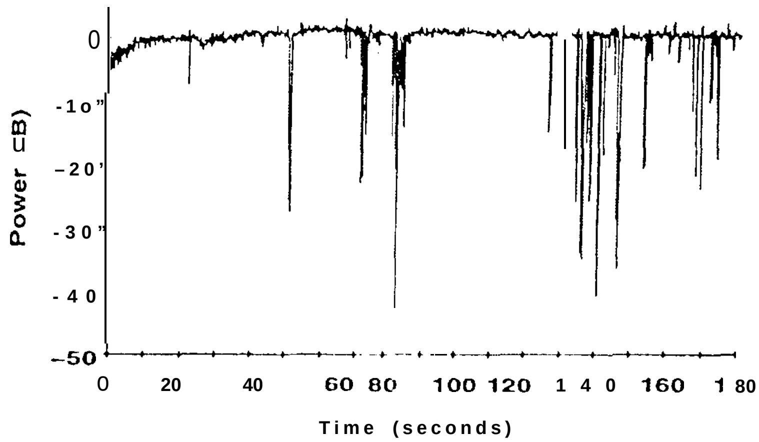

Figure 3-2 Typical Propagation Data From Mobile Tests

For this experiment, a total of nine days worth of data was collected under highway and suburban conditions.

3.3.1 **Call Success/Failure Analysis**

A summary of the overall success/failure of these tests as recorded during the experiment is presented in Table 3-1. Six different call scenarios, as described from the table headings, were considered. The recorded information included the total number of calls made for each scenario, the total number of successful calls made, and the total number of failed calls, A successful call is defined as one in which clear voice was established, the transition to secure communications was successful, and the transition back to clear communications was also successful. A breakdown of the different types of failures that occurred is also provided in this table. A majority of the completely successful calls were established during highway tests, as expected. Often during the Rose Bowl (suburban) tests, considerable shadowing or blockage was experienced during a key transitioning period for the communications link, The bottom portion of this table expresses the results normalized in the form of percentages so that direct comparisons can be made.

It has been surmised that a majority of the failed calls was a direct result of an interface problem between the DGU and the AMT TC, thus skewing the presented statistics. It was later discovered that the associated interface logic of the AMT 1 C is level triggered while the DGU's interface logic is edge triggered. Later tests of this setup, using compatible interface designs provided much more reliable results. Examination of this data (excluding the DGU interface failures) shows that for data rates of 4.8 kbps, the call success rate ranged from 76 percent to 91 percent. The 2.4 kbps data rate case was not as successful, with success rates ranging from 50 percent to 52 percent,

Table 3-1 Call Success/Failure Data

	Fixed to Mobile, 4.8 kbps	Mobile to Fixed, 4.8 kbps	PSN to Mobile, 4.8 kbps	Mobile to PSN, 4,8 kbps	PSN to Mobile, 2.4 kbps	Mobile to PSN, 2.4 kbps
Total Calls	**23**	**42**	**44**	**48**	**11**	**24**
Successful calls	**18**	30	13	25	3	11
Failed Calls	**5**	**12**	**31**	**23**	**8**	**13**
DGU Interface failures	3	9	28	15	5	3
Failed Transition to secure	2	2	2	2	0	0
Failed Transition to clear	0	1	1	1	0	0
Misc. Failure	0	0	0	5	3	1 0
% Successful calls	**78%**	**71%**	**30%**	**52%**	**27%**	**46%**
% Failed Calls	**22%**	**29%**	**70%**	**48%**	**73%**	**54%**
% DGU Interface failures	13%	21%	64%	31%	45%	13%
% Failed Transition to secure	9%	5%	5%	4%		
% Failed Transition to clear		2%	2940	2%		
% Misc. failures				*10%*	27 0/0	420/.

The poor performance of the setup at 2,4 kbps data rate, as compared to the 4.8 kbps data rate case, could be attributed largely to the lower data rate case being more susceptible to shadowing events which corrupted the data stream. This in turn caused the DGU to malfunction. A shadowing event of a given length (and depth) would effect 2.4 kbps communications more severely than it would 4.8 kbps. Clearly, a more pronounced effect would be experienced if this event were to occur during the transmission of synchronization information present in the voice compression algorithms associated with the DGU.

Furthermore at 2.4 kbps, shadowing events presented themselves on the audio channel as clicks and these were in turn interpreted by the PSN switch as hookflashes which subsequently caused communications to fail. This phenomena also occurred at 4.8 kbps, but much less frequently. The two most common results of these hookflashes were to hang up the PSN connection, or to “click over” so that three way calling could begin. All attempts at actually using the hookflash options failed. This appears to be a limitation of the DGU.

3.3.2 **Voice Quality Analysis**

To analyze the voice quality, a subjective letter grade was assigned to each call in both the clear and secure mode, based on the scale described in Table 3-2. The plus and minus ratings are not assigned any particular description. This is to allow the experimenter to make subjective decisions as to when a call is a little better or worse than the straight definition,

From this grading system, a standard 4 point grade point average (GPA) was implemented to numerically quantify these results. In order to remove any inconsistencies that are inherent to subjective ratings, the results were averaged over all calls with a particular call scenario so that trends could be noted. These averages are presented in Table 3-3. Note that if no clear voice communications were established for a particular call, then that call was not considered in the data. Similarly, if no secure voice communications were established for a particular call, then that call was not considered in the secure voice averages,

Table 3-2 Definitions of Qualitative Voice Grades

Grade	GPA	Description
A	4.0	Voice quality is equal to the quality obtained over a standard, terrestrial secure telephone link at the same data rate being considered.
B	3.0	Hiss and minor echo are apparent, Caller is still easily understandable and voice is recognizable.
c	2.0	Hissing, pops/clicks, echo present. Communications are occasionally interrupted,
D	1.0	Communications frequently interrupted and callers must repeat information frequently,
F	0.0	Effective communication is not possible.

From Table 3-3, it is obvious that the clear voice case did not provide as high a quality signal as the secure communications case. This quality discrepancy can be directly 'attributed to different implementations of the speech compression algorithms in DGU clear voice communications and STU-III secure voice communications. There were no significant trends that were dependent upon which terminal initiated the phone call.

Table 3-3 Voice Quality Averages

Call Scenario	Average Voice Quality Rating
2400 bps, fixed station initiates, clear voice	3.00
2400 bps, mobile terminal initiates, clear voice	2.93
4800 bps, fixed station initiates, clear voice	3.09
4800 bps, mobile terminal initiates, clear voice	3.02
2400 bps, fixed station initiate, secure voice	4.00
2400 bps, mobile terminal initiates, secure voice	4.00
4800 bps, fixed station initiates, secure voice	3.95
4800 bps, mobile terminal initiates, secure voice	3.67

3.4 **Experiment Conclusions**

This experiment suggested that a satellite system similar in design to ACTS would be a viable communication technology enhancement for NS/EP users. The satellite field tests provided very good results - albeit not without its share of anomalies. Reliable clear voice and secure communications were established at both 2.4 kbps and 4.8 kbps. The link proved to be highly robust for both cases of communications, however, at both of these data rates, the link was highly susceptible to failures if a significant amount of shadowing was experienced during a transition from clear voice to secure voice communications or vice versa, Also, occasionally the setup would provide inconsistent performance during call setup or tear down, This was a direct result from the interface design between the AMT TC/DGU/STU-III. This design has been improved upon, and initial test results suggest that this intermittent behavior has been eliminated.

4. PSN RESTORATION WITH THE ACTS **T1-VSAT**

4.1 **Objectives**

The overall goal of this experiment was to demonstrate the ability of an ACTS-like system in conjunction with T1-VSAT's to implement NS/EP user priority/precedence, communications security, and PSN access requirements. Specific user applications addressed by this experiment included point-to-point, secure voice, and user access to the PSN. This experiment considered

[1] 4.8 kbps worked better than 2.4 kbps in the mobile environment.

restoration of communications for NS/EP users if their PSN inter-exchange carrier switching (ICS) facilities becomes disabled,

In particular, this experiment demonstrated:

1) the integration of ACTS and the PSN
2) the capability of the ACTS' terminal interface equipment (TIE) with appropriate software to recognize and provide priority treatment for NS/EP traffic
3) the feasibility of providing PSN access for NS/EP traffic through an ACTS terminal
4) the feasibility of providing communications security for NS/EP traffic over ACTS
5) the potential capability for rapid deployment of ACTS terminals for communications restoration.

4.2 Experiment Setup

The test configuration for the PSN restoration experiment using ACTS is shown in Figure 4-1. Two T1-VSAT'S were required at two separate locations in the ACTS spot beam coverage area (Pasadena, California and Reston, Virginia), and each was positioned in proximity to private branch exchange (PBX) equipment. The terminal at each location was interfaced to PBX equipment with a standard PSN T1 interface via the ACTS TIE. End user equipment (e.g., telephone base sets) was also connected to the terminal TIE. With this configuration, users connected directly to the terminal, PBX users, and PSN users accessed the terminal via both direct TIE connections and a PSN T1 connection, thus permitting direct user access to ACTS. End-to-end communications traffic that bypassed the inter-exchange network was then established through ACTS.

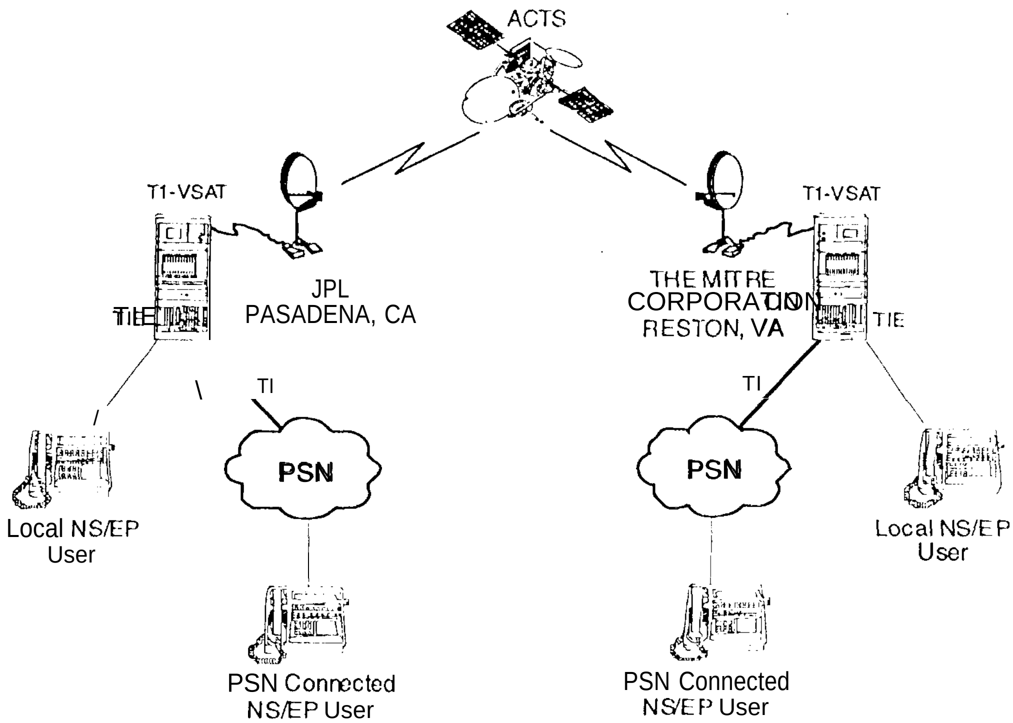

Figure 4-1 PSN Restoration Experiment Configuration

The ACTS T1 VSAT Terminals were designed and developed by Harris Corporation under contract to NASA Lewis Research Center (LeRC) [4]. These terminals can be operated with either a 1.2 m or 2.4 m reflector antenna, but of the terminals have been outfitted with a 1.2 m reflector antenna. The satellite communications link can successfully be maintained in this configuration in all but the most severe environmental conditions. Two of these terminals were directly purchased by the

NCS for use during the ACTS Experiments Program, The NCS has contracted JPL and the Mitre Corporation to operate these terminals during these experiments to evaluate the possibility of using this equipment to meet communication requirements during a disaster recovery or NS/EP situation,

The T1 VSAT Terminals have been designed to provide communications at data rates up to 1.544 Mbps (T1 data rate), The configuration of these terminals is flexible enough to operate as a "trunked" communications pipeline, providing the full operational bandwidth for a single use. In a channelized mode, up to twenty-eight, 64 kbps voice or data channels may be set up, The terminal's architecture is Time Division Multiple Access (TDMA) based, operating at a burst communications data rate of 27.5 Mbps. Additional link margin is built into the terminal design through the use of coding. Normal operation of the terminal is with an uncoded Binary Phase Shift Keying (BPSK) modulation scheme. If severe weather conditions should limit the terminal's availability, the terminal may also be operated in a coded BPSK modulation scheme. The modulation scheme used with this terminal is a rate 1/2, constraint length 7, convolutional code with Viterbi Decoding. Depending upon the exact location of the terminal, this coding scheme provides between 6- 10 dB of additional link margin while decreasing the data throughput by half.

The T1 VSAT terminal consists of two major components: (1) the outdoor equipment shown in Figure 4-2 and (2) the indoor equipment. The outdoor equipment consists of three different subsystem components: (1) the antenna, (2) the transmitter, and (3) the receiver, The antenna equipment consists of the reflector and feed assembly mount, diplexer, and filters. The transmitter includes the up-converter, a 15 GHz RF power transmitter, and a 30 GHz High Power Frequency Doubler (HPFD). The receiver includes the 20 GHz receiver/Low Noise Amplifier (LNA) and down-converter. The indoor equipment consists of two subsystems: (1) the frequency generation and control module and (2) the terrestrial interface equipment (TIE). The frequency generation and control equipment includes the clock and frequency oscillators, timing, and control microprocessors, control computer, and monitoring and control interface equipment. The TIE consists of the electrical and signaling interface equipment required to interface to the end user's telecommunications equipment.

Three series of calls were placed. The first series tested all aspects of the communications link with the exception of call pre-emption and remote PIN verification capabilities. Each call was evaluated for successful completion, voice quality, and the ability to transition from clear to secure voice and back. Four types of calls were placed for this series, all passing through ACTS. These calls could either be standard calls or secure calls. A diagram illustrating

(INSERT PHOTO HERE)

Figure 4-2 TI VSAT Outdoor Equipment

the four types, labeled Type 1 through Type 4, is shown in Figure 4-3. The experimental results were reported with the observer at the right hand side of the diagrams in Figure 4-3.

The second *series* of calls tested the call prioritization/pre-emption capabilities of the setup. The third series of calls was intended to assess the functionality of the remote PIN verification feature. Further details about the test procedures for this experiment can be found in [1].

4.3 **Data Summary**

Data was taken for the three separate segments of the experiment. The data for the three series of tests discussed above is summarized in the remainder of this section.

4.3,1 Call Progression, Voice Quality, and Secure Communications

For the progression tests, in all cases, it was possible to place the desired call. Occasionally, some minor difficulties were encountered. The most noteworthy of these difficulties related to the dialing “timing. ” [t was necessary to complete dialing without significant pauses. Delays exceeding approximately 5 seconds caused the timeout (intercept) tone to be activated. In the case of dialing out to the PSN, it was necessary to either dial the PSN phone number immediately after the other digits in the call string (i.e., no pauses of more than 1 or 2 seconds),

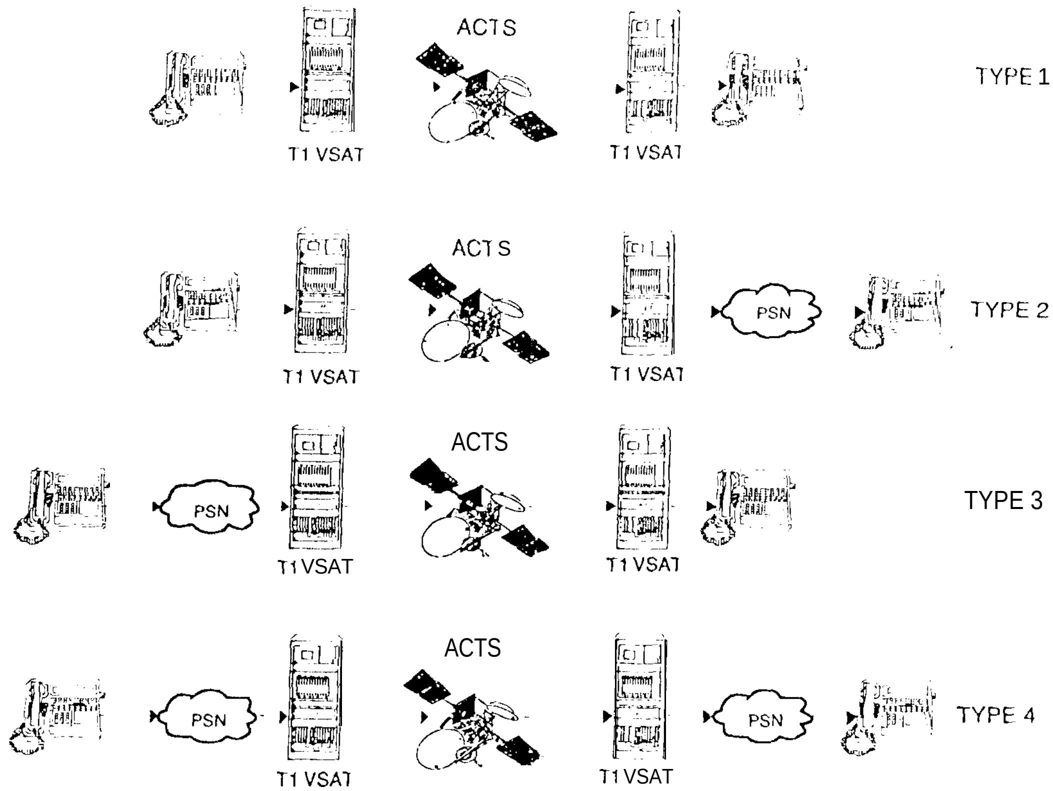

Figure 4-3 Call Type Configurations

or else, wait until the PSN dial tone was heard before dialing the last numbers. If the PSN phone number was dialed after too long a pause, but before the dial tone, the digits needed to be redialed upon receipt of the dial tone.

To analyze the voice quality, a sequence of all four types of calls was established. These calls were all established at a low bit error rate (on the order of 10-8). To analyze the voice quality, a subjective letter grade was assigned to each call based on the same scale used for the Mobile Secure Communications Experiment listed in Table 3-2.

As in the Mobile Secure Communications Experiment, in order to minimize any variations due to the subjective ratings, the sequences were repeated ten times and the results averaged over all types of calls to determine trends in voice quality. The averages for the trials in the sequence are presented in Figure 4-4. Note that the data on several of the sequence numbers are not presented in the figure. This is because the data analyzed anti presented here is restricted to the calls either received at or placed from the JPL facility. For the data presented here, roughly half of the calls either initiated or terminated at the Mitre facility. Note also that the last four groups of calls in the sequence were Type 4 secure calls. From this figure, we see first that all voice quality ratings fall between 3.0 and 4.0 (i.e., A-B) levels. This indicates that for all calls, including the secure calls, the voice quality was quite good.

By dividing the calls into the four different types (excluding the secure calls), a specific trend became apparent. This trend is presented in Figure 4-5, where the call type versus the average quality over all of the calls of that type are plotted for the non-secure calls only. The trend clearly indicates improved circuit quality with additional connections to the PSN. Given the low bit error rate that the tests were performed at, it is believed that this improvement was a result of the high quality echo cancelers used by the PSN switch. Apparently, the PSN TI echo cancelers are more efficient than the TIE's line card echo cancelers at removing echoes and periodic noise in a low bit error rate environment. Thus, those circuits which had more PSN connectivity had better quality. Furthermore, far-end PSN connectivity had a greater positive effect on voice quality than did near-end connectivity. This can be explained by noting that the echo cancelers placed at the far end prevent the near-end from hearing an echo of their transmission, and visa versa.

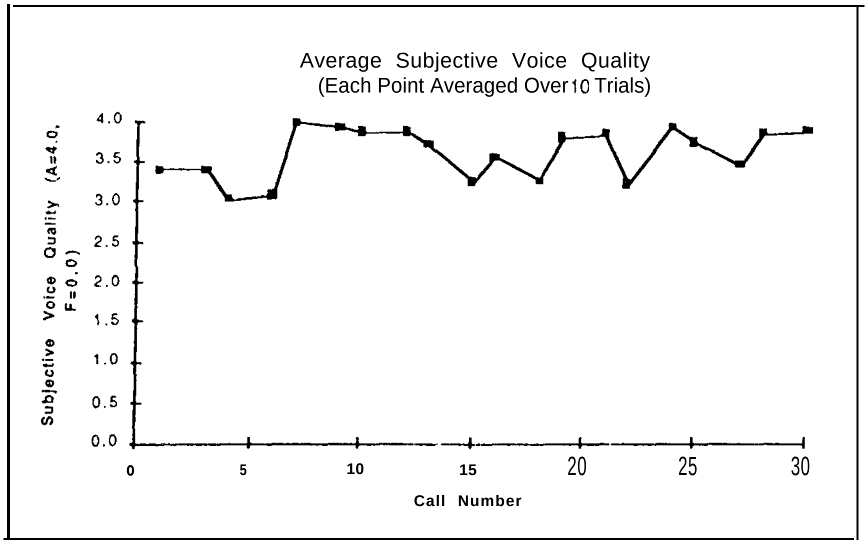

Figure 4-4 Average Voice Quality Ratings

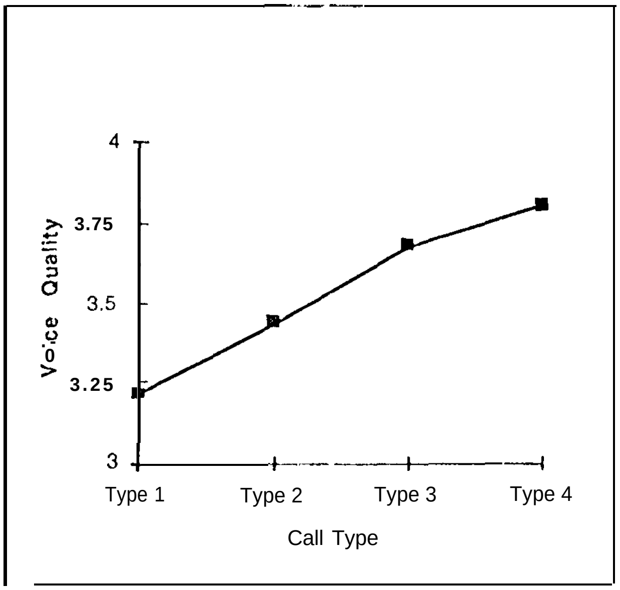

Figure 4-5 Voice Quality Ratings for the Different Types of Calls

In an effort to determine the effects bit errors on the link quality, an additional test was performed. In this test, the T1 VSAT antenna at JPL was depolarized so that the bit error rate of the channel was degraded from the nominal 10^{-8} to approximately $5x10^{-5}$. The results differ slightly from the previously reported results in that only a single sequence of data was gathered versus the ten that were averaged together for the previous results. A graphical comparison of these results with the previous results is presented in Figure 4-6. Figure 4-6 indicates a general degradation in voice quality for an increased BER. However, the change was relatively small, and communication was still readily available. Additionally, no change in the ability to establish calls was noted.

Of particular note, the voice quality degradation for the four call types was not uniform. More specifically, the calls that originated or terminated with the PSN suffered more severe degradation than those that did not. Increased degradation also was experienced during a number of PSN connections, as depicted in Figure 4-7. This effect may be caused by PSN echo cancelers that are more sensitive to noisy data channels than are the line card echo cancelers. This is understandable when considering that the telephone company minimum operating BER is specified to be 10^{-6}, and is typically 10^{-8}

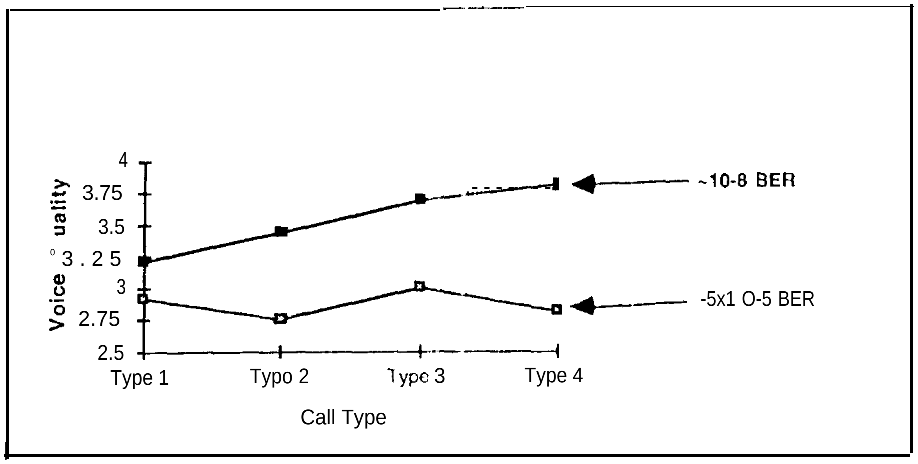

Figure 4-6 Voice Quality Comparison for Low and High BER Channels'

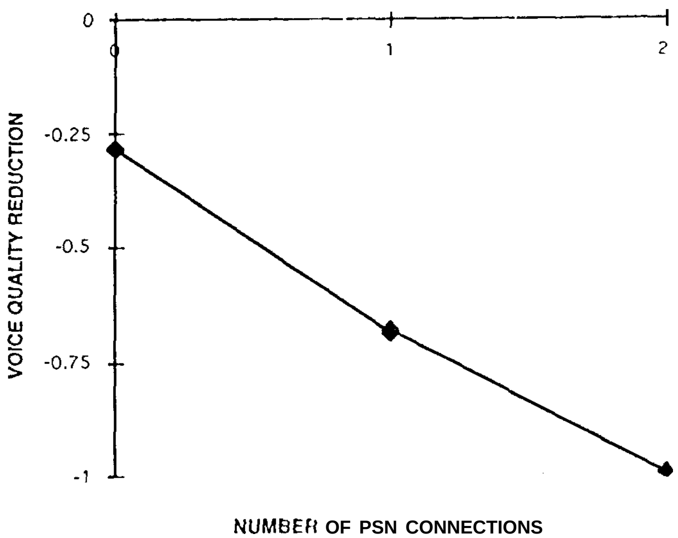

Figure 4-7 Voice Quality Reduction Vs. No. of PSN Connections (--$5x10^{-5}$BER)

4,3.2 Call Prioritization and Pre-Emption

The TIE call priority software is designed to allow priority access to the ACTS network by persons with high level personnel identification numbers (PIN's). If no circuits are free, and if a lower priority call exists, it will be pre-empted (i.e., disconnected) to make room for the higher priority call. In order to test this capability, the following steps were taken. First, to fill the capacity of the satellite channel, a 24 data channel call was placed with the highest priority F'IN. Then 2 of the 4 line card phones were used to call the other stations involved in the test utilizing the highest priority PIN, These lines were used for coordination of the experiment, Two lines then remained available for experimentation.

The sequence of twenty-six calls for this part of the experiment was designed to begin with the lowest level of priority and proceed to the highest priority level, sequentially pre-empting calls in the process, Some calls were also placed with lower priority to verify that no higher priority calls would be incorrectly pre-empted. Calls 1 - 15 concentrated on pre-empting calls one priority level below that of the calling party (i.e., priority 4 pre-empts priority 5, priority 3 pre-empts priority 4, etc.). Calls 16 - 26 tested calls that pre-empted existing calls that were 1 or 2 levels below that of the calling party.

For calls 1 -15, there were no notable deviations from the expected results. For calls 16-26, a deviation from the expected results was experienced. Specifically, call 19 did not behave as expected. At the time of call 19 (priority 2), calls 17 (priority 4) and 18 (priority 3) were up, It was expected that the lowest priority call, number 17 would be pre-empted by call 19, but instead, call 18 was pre-empted at the satellite channel, and then call 19 was connected to a busy signal or transferred to a receptionist at ES05 (the Mitre Corporation's Earth Station 5) site because the PSN number was still busy on call 17.

4.3.3 **Remote PIN Verification**

The remote PIN verification portion of this experiment was executed according to plan. In all cases, the PIN was successfully verified. It should be noted that there was a consistent delay of about 15-20 seconds between the dialing of the remote PIN and the receipt of a dial tone. This delay was enough to cause many users to think the call had failed. Thus, in operations, all users should be made aware of this delay.

4.4 **Experiment Conclusions**

During the course of the experiment, several important conclusions were reached, The most significant of these is that an ACTS-like system would be useful for many NS/EP situations. The system, as tested, provided high quality, consistent secure and clear voice communications. Furthermore, it was possible to maintain data communications with a very low bit error rate.

Overall, the PSN restoration experiment went very well. The voice quality was consistent and of high quality, even when the transmitted signal was attenuated by de-polarizing the antenna. Establishing calls was easy and relatively efficient. T-here was a small learning curve regarding the dialing timing that had to be overcome. This could be eliminated in any future ACTS-like systems simply by extending the dialing time-out time from 5 seconds to some reasonably larger amount of time. Another help in removing the learning curve would be to buffer the dialed digits as they are being keyed, so that the timing of the dialing of the PSN phone number would be less critical.

When used for secure communications, the T1VSAT performed as well as any standard terrestrial PSN circuit. It was found to be quite simple to establish secure communications at all data rates tested (2400, 4800, and 9600 bps). The voice quality when in secure mode was identical to that of standard terrestrial STU-III communications,

The call prioritization/pre-emption part of the experiment went well. The only area of concern regards the pre-emption of lower priority calls, When a higher priority call is made over a full channel, the TI VSAT software searches the call list until a lower priority call (not necessarily the lowest) is found, and then that call is pre-empted. In operations, the problem can be addressed by instructing mid-level priority users that in the event of pre-emption, they should immediately attempt to reestablish their call to see if a lower priority call can be pre-empted.

Remote PIN access to the ACTS system also worked well. It is important to note that in operations, there is a 10 to 20 second delay between the entering of a PIN and receiving a dial tone. It is a straightforward engineering problem to reduce this waiting time, and it is expected that in an operational system this would be done, In every case, the remote PIN access operated exactly as expected.

5. PSN TRUNKING WITH T1-VSAT'S

5.1 Objectives

The overall goal of this experiment was to demonstrate TI trunking with ACTS resources. The specific user application addressed by this experiment was point-to-point clear channel T1 data communications. This experiment dealt with connectivity reconstitution between carrier switches and employed T1 test equipment to perform BER tests.

5.2 Experiment Setup

A similar test configuration to that presented in the previous section was used for this second experiment Two T1 VSAT terminals were required at two separate locations in the ACTS spot beam coverage area, and each was positioned in proximity to a Fireberd 6000 BER Tester that was used to simulate user traffic (one each at JPL and the Mitre Corporation). The terminal at each location was then connected to the test equipment using a standard TI interface. Point-to-point T1 trunking traffic routing between these terminals through ACTS was then established at varying rates, and each test set monitored and analyzed data generated by the other. There was no PSN connectivity in this experiment.

The BER tester was used to provide the AMI/D4 and B8ZS/ESF data format/framing combinations that were tested. The test set was also able to provide a variety of bit test patterns.

Statistics were recorded for Bit Errors, the BER, Error Free Seconds, Bipolar Violations (BPV's), and Framing Errors. Error free seconds indicate, in rough fashion, the nature of the errors that occur (i.e., bursty or uniformly distributed). Framing errors typically occur in a high BER environment, a situation where bit slips can occur. BPV's are caused by faults in the TIE and are not caused by bit errors. Further details about the test procedures for this experiment can be found in [1].

5,3 Data Summary

Several trials were run with different channel framing formats and data types, Statistics were then collected in the following categories: error free seconds, BPV's, framing errors, bit errors, and the BER.

5.3.1 Bit Errors and Errored Seconds

During the course of this experiment, it became obvious that very few bit errors were occurring. BER's of better than 10^{-9} were regularly recorded, and BER's of 10^{-10} were not uncommon. In only two instances did the BER increase above 10^{-8}. These instances occurred when large bursts of errors were present. Examination of the data showed that when bit errors did occur, they were separated, and thus, not bursty (as would have been expected). A typical plot of these errors as a function of time is provided in Figure 5-1.

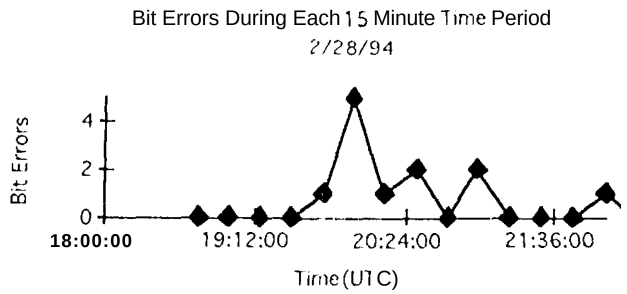

Figure 5-1 Typical Bit Error Count

The choice of framing format (i.e., ESF or D4) and bipolar data format (i.e., B8ZS or AMI) did not have any apparent effect on the results of these tests. The choice of BER test pattern also did not have any apparent effect upon the results of these tests.

5.3.2 Bipolar Violations and Framing Errors

There were no BPV'S or framing errors recorded during data collection for this test.

5.4 Experiment Conclusions

Once the terminal was brought on-line, the experiment went well. There were some deviations in received signal power that appeared to be periodic over the course of any given 24 hour period. These fluctuations are the result of several effects including spacecraft movement, the changing temperature of the antennas, varying effective sky temperature due to the position of the sun in the sky relative to the satellite's position, etc. These fluctuations had no noticeable effect on the BER tests that were performed. The BER consistently maintained a level of 10^{-8} or better, This is the same level that the local telephone companies list as their typical BER. It is also much better than the minimum local telephone company specification of 10^{-6}.

In general, it appeared that there were no noticeable communication degradation's with the ACTS system that occurred as a result of typical, mild weather patterns. During the tests, no severe weather events ever occurred, and so, this remains an area of uncertainty. Some light rains were experienced during these tests, but the overall link margin for this configuration far exceeded any of these minor signal degradation and effects.

The format of the data (i. e., B8ZS/ESF and AMI/D4) being sourced to the T1VSAT's also had no discernible effect on the BER. These formats do not actually check the satellite link performance, but instead, check the performance of the TIE. Ibis is because the TIE, upon receipt of the T1 data stream, breaks the T1 frame down into its constituent channels and formats the voltage levels for transmission across the satellite link. At the receive side, the inverse function is performed.

6. **ISOLATED USER** ACCESS WITH **T1-VSAT'S**

6.1 **Objectives**

The overall goal of this experiment was to demonstrate the ability to support secure isolated NS/EP user network communications and PSN access with ACTS resources. Specific user applications addressed by this experiment, therefore, included secure and clear voice communications over the PSN. This experiment addressed the restoration of damaged local exchange, carrier and Inter-exchange Carrier Switching (ICS) connectivity.

Similar to the previous two experiments, this experiment demonstrated the potential benefits of a system like ACTS in the NCS' support of communications traffic for emergency situations such as earthquakes, hurricanes, and severe storms, and for low intensity U.S. military operations. In either scenario, a transportable TI VSAT can be deployed to an isolated area to permit remote users to communicate through ACTS to their headquarters, which in this case, was interfaced to another T1 VSAT. The purpose of this experiment was to demonstrate:

1) ACTS capability of routing individual NS/EP narrowband traffic from remote locations to a PSN switch
2) ACTS capability of supporting a network of individual NS/EP users
3) feasibility of providing communications security
4) the capability of the T1 VSAT TIE to recognize and provide priority for NS/EP traffic.

6.2 **Experiment Setup**

Two network configurations were demonstrated by this experiment. In the first, isolated NS/EP user communications were supported in a multi-node network that bypassed the PSN. In the second, the isolated NS/EP users were provided access to the PSN in a manner similar to that demonstrated in the PSN restoration experiment,

Three TI VSAT terminals were utilized (one each at JPL, the Mitre Corporation, and NASA LeRC located in Cleveland, Ohio). One terminal (located at the Mitre Corporation) was positioned in proximity to a PBX in the ACTS spot beam coverage area. The other two terminals were placed in the ACTS coverage area at other selected locations. The terminal positioned by the PBX was interfaced to the PSN. End users were equipped with ST U-111 telephones to attain communications security.

The priority management for this traffic was implemented by integrating appropriate software into the TIE control software. Further details about the test procedures for this experiment can be found in [1].

6.3 **Data Summary**

The types of data that were recorded are specified in [1], This data is similar to the portion of data from Experiment 1 that involved a TIE connected user, Specifically, the calls that were made conformed to call types 1, 2, and 3, as specified in Section 4.3.1 of this document,

Two primary types of data were collected: 1) subjective voice quality ratings, and 2) call prioritization and pre-emption functionality.

6.3.1 Voice Quality

The method that was used in the Mobile Secure Communications experiment to rate voice quality was used in the Isolated User Access experiment. Namely, a letter grade was assigned by the experimenter to subjectively rate the quality. A similar grading system was used to numerically quantify the results, and finally, the results for 10 separate trials were averaged. The average results are presented in Figure 6-1.

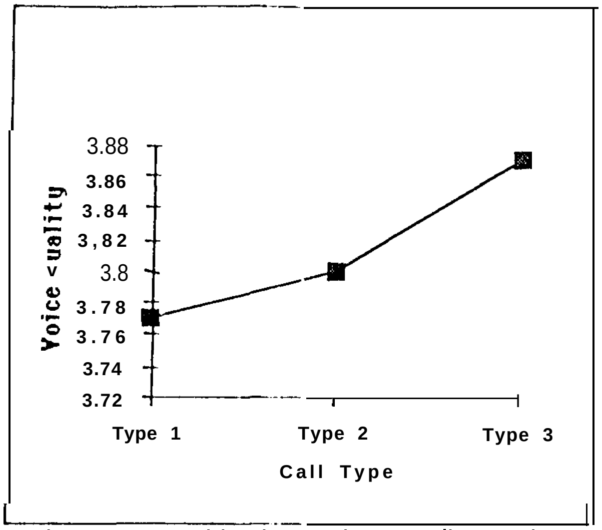

Figure 6-1 Subjective Voice Quality Rating

For all three types of calls, the quality was rated at about an A- quality. However, there is some deviation between results. Type 1 calls, the only type without PSN connectivity, recorded the worst results. Type 2 calls, which have near end PSN connectivity, were rated as marginally better than type 1 calls. And finally, Type 3 calls, those with far end PSN connectivity, were rated best.

This is consistent with the test results that were recorded in the PSN restoration experiment. It is believed that this improvement was a result of the high quality echo cancelers used by the PSN switch. Apparently, the PSN, TI echo cancelers are more efficient than the TIE line card echo cancelers at removing echo's. Thus, those circuits with PSN connectivity had the best quality, Furthermore, the circuits with the PSN connectivity on the far-end had better quality than those with near-end PSN connectivity only. This can be explained by noting that echo cancelers placed at the near-end prevent the far-end from hearing an echo of their transmission, and visa versa.

6.3.2 **Call Prioritization and Pre-emption**

The call prioritization/pre-emption part of this experiment produced results as expected. There were no failures and no unexpected results. Note that only level 1 pre-emptions (i.e. the pre-empting call had priority n while the pre-empted call had priority n+1) were tested,

6.4 **Experiment Conclusions**

This experiment showed that NS/EP scenarios involving remote users can be addressed effectively with an ACTS-like system. Voice quality was quite good, and call progression proceeded logically and efficiently. Furthermore, it was easy to establish and maintain secure communications with STU-III's.

7, T1 VSAT PROPAGATION DATA

In an effort to understand the effects of the propagation channel on the T1-VSAT experiments, various propagation data collected during the experiment times were examined. This data indicates that there are certain daily phenomena that affect the performance of the terminals. In addition, the effects of weather are also examined.

Certain daily phenomena were observed during these T1 VSAT experiments. Typical plots of this cyclical phenomena are provided in Figure 7-1 and Figure 7-2. These fluctuations can be attributed to such factors as heating and cooling of the satellite and of the terminal. During these experiments, as the sun rose (at approximately 18,5 hours UTC), the Eb/No exhibited a decrease, These cyclical changes that were observed had no significant impact on the T1-VSAT experiment because the typical E_b/N_o operated at was approximately 25 dB. The ±1dB cyclical effect seen had little observed impact on the received BER.

Figure 7-1 Example of Daily Signal Fluctuation. Data Recorded March 2, 1994

Figure 7-2 Example of Daily Signal Fluctuation. Data Recorded March 3, 1994

Unfortunately, no significant rain fade events occurred during the experiments. However, this is a consideration that should not be ignored. For most rain fades, a T1-VSAT satellite network rain fade compensation algorithm is implemented, This algorithm implements coding to provide up to 6dB of additional performance margin. An example of a typical rain fade event is provided in Figure 7-3. This event occurred on March 19, 1994, when heavy showers were experienced at JPL The plot shows fading by as much as 8 dB. The missing portion of the plot is due to the data being unavailable for that portion of time.

For purposes of comparison, the process of depolarizing the antenna to reduce the BER from 10^{-8} to approximately 5×10^{-5} was discussed in Section 4.3.1. This corresponded to a reduction in E_b/N_o by about

8,5 dB from approximately 25.5 dB to 17 dB. Thus, this depolarization example provides a good indication of the type of performance that can be expected during rain fades of the nature shown in Figure 7-3 if the rain fade compensation algorithm is not used. Note that the terminal did not go into coding during the depolarization test,

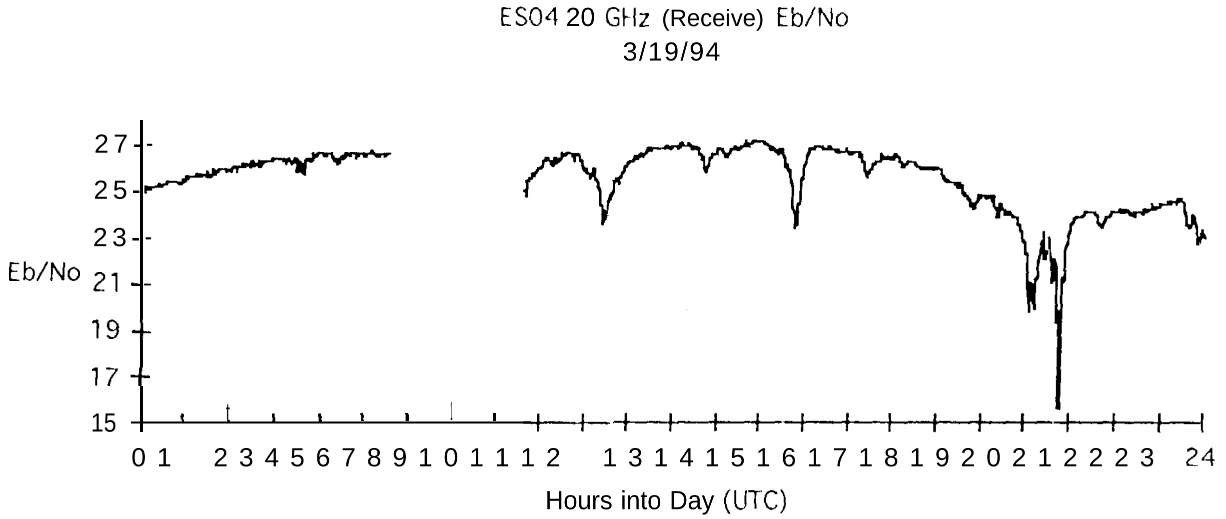

Figure 7-3 Example of the Effects of Rain Fading. Data recorded March 19, 1994

8. CONCLUSIONS

The various tests that have been accomplished utilizing ACTS, the AMT, and the TI VSAT have proven to be highly successful. Full-duplex secure voice (mobile) at 4.8 and 2.4 kbps was implemented with the AMT. Several improvements in the setup of the AMT has allowed for an increase in the overall throughput communications capacity to approximately 512 kbps. With this setup, multiple channels of clear and secure voice, as well as a single compressed video link are possible.

Full-duplex T1 (1 .544 Mbps) capabilities were possible with the T1VSAT. Repackaging these fixed terminals onto transportable platforms (e.g., trailer and/or van) will allow the NCS to utilize them in an operational scenario. The NCS is coordinating arrangements through NASA to utilize these terminals and ACTS during any future disaster situations in the continental United States,

9. **REFERENCES**

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10. ACKNOWLEDGMENTS

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